AC 2010-2334: DEVELOPING VLSI CURRICULA IN ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

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Developing VLSI Curricula in Electrical and Computer Engineering Department

Abstract

VLSI (Very Large Scale Integrated Circuits) technology has enabled the information technology revolution which greatly changed the life style of human society. Computers, internet, cellphones, digital cameras/camcorders and many other consumer electronic products are powered by VLSI technology. In the past decades, the VLSI industry was constantly driven by the miniaturization of transistors. As governed by Moore's law, the number of transistors in the same chip area has been doubled every 12 to 18 months. Nowadays, a typical VLSI CPU chip can contain millions to billions of transistors. As a result, the design of VLSI system is becoming more and more complex. Various EDA tools must be used to help the design of modern VLSI chips. The semiconductor and VLSI industry remain strong needs for VLSI engineers each year. In this paper, efforts in developing systematic VLSI curricula in Electrical and Computer Engineering department have been proposed. The goal of the curricula is to prepare students to satisfy the growing demands of VLSI industry as well as the higher education/research institutions.

Modern VLSI design needs a thorough understanding about VLSI in device, gate, module and system levels. We developed CPEG/EE 448D: Introduction to VLSI to give students a comprehensive introduction about digital VLSI design and analysis. In this course, various EDA tools (such as Mentor Graphics tools, Cadence PSPICE, Synopsys) are used in the course projects to help students practice the VLSI design. In addition, analog and mixed signal circuit design are becoming more and more important as MEMS (Microelectromechanical Systems) and Nano devices are integrated with VLSI into System-on-Chip (SoC) design. We developed CPEG/EE 458: Analog VLSI to introduce the analog and mixed signal VLSI design. As portable electronics (e.g. laptops, cellphones, PDAs, digital cameras) becoming more and more popular, low power VLSI circuit design is becoming a hot field. We developed CPEG/EE 548: Low Power VLSI Circuit Design to introduce various low power techniques to reduce the power consumption of VLSI circuits. Nowadays the VLSI circuits can contain billions of transistors, the testing of such complex system becoming more and more challenging. We developed CPEG/EE 549: VLSI Testing to introduce various VLSI testing strategies for modern VLSI design. In addition to the design and testing, we also developed EE 448: Microelectronic Fabrication to introduce the fabrication processes of modern VLSI circuits. With such a series of VLSI related curricula, students have an opportunity to learn comprehensive knowledge and hands-on experience about VLSI circuit design, testing, fabrication and EDA tools. Students demonstrate tremendous interests in the VLSI field, and all the VLSI courses are generally over-subscripted by students in the early stage of enrollment. Many students are also doing the VLSI graduate research and published various papers/posters in the VLSI related journals/conferences.

1. Introduction

VLSI (Very Large Scale Integrated Circuits) has been one of the most important technologies developed in 20th century. All the electronic products we use nowadays are enabled by VLSI technology, such as cell phone, digital camera, camcorder, MP3 player, radio, TV, speaker, refrigerator, car electronics, etc. Furthermore, VLSI technology has enabled digital computers which have brought our human society into information era. Every day we browse internet, receive/send emails, chat with families and friends through online video conferences, prepare powerpoint presentations. Information technologies have brought us great convenience in our everyday life. Without VLSI technologies, all these would not have been possible.

Since the world's first transistor was invented at Bell Labs (USA) in Dec. 16, 1947, it has ignited a series of profound technology revolution to our life style. Transistors are the basic building blocks for VLSI circuits. The first transistor was very bulky and power-consuming. During the last decade, the VLSI industry has made continuous efforts to keep shrinking the size of the transistors, so that more and more transistors can be built into a single VLSI chip to make it more and more powerful [1]. Gordon Moore, co-founder of Intel Corporation, predicted in 1965 that the number of transistors per square inch on an integrated circuit would be doubled every 12 to 18 months. This so-called Moore's law [2] has governed the trends in VLSI industry for the past decades. The world's first transistor based radio, the Regency TR-1, was released to market for $49.99 in 1954. The radio contains only four transistors. In 2003, Intel developed Pentium 4 microprocessor which contained 55 million transistors. Recently, Intel announced that the world's first 2-billion transistor microprocessor, named Itanium processor, will be produced in 2010 [3]. Smaller transistor size means lower cost, faster speed and lower power consumption. Nowadays, the minimum feature size of commercial VLSI technologies has been shrunk into deep submicron and nanometer domain. Furthermore, according to ITRS (International Technology Roadmap for Semiconductors) 2009 summary [4], MEMS (Microelectromechanical Systems) and Nanotechnology devices are being integrated with VLSI circuits into a System-on-Chip (SoC), as shown in Figure 1. Nanoelectronics will bring revolutionary changes to current silicon-based CMOS VLSI technology, and maintain Moore’s law in the following decades [5].

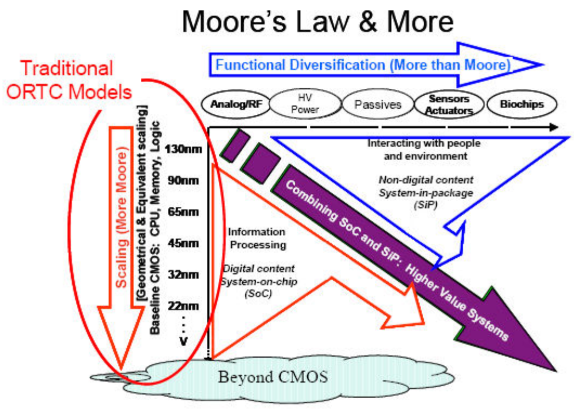

Figure 1. Moore’s law and more [4]

As more and more transistors are built into a single VLSI chip, this also bring tremendous challenges to the design, fabrication and testing of modern VLSI circuits. The early generation of small-scale ICs containing tens or hundreds of transistors could be manually designed by engineers in the physical level. However, nowadays a typical VLSI may contain millions of billions of transistors. The complexity can no longer be handled by individual engineers manually. Computer software (EDA tools) must be used in the design of complex VLSI system design. For the complex VLSI digital system, a top-down instead of traditional bottom-up design strategy should be used. The testing of modern VLSI circuits can no longer be exhaustively tested due to extremely long test time. As a result, new test strategies must be developed to test the modern VLSI circuits efficiently. Students need to be trained with systematic knowledge and skills in various VLSI EDA tools in order to meet the challenges as VLSI engineers in modern VLSI industry. In this paper, the experience of developing systematic VLSI curricula at graduate level in Electrical and Computer Engineering department in University of Bridgeport is shared. A series of VLSI courses have been developed to cover various fields in VLSI technology. As an introductory course, CPEG/EE 448D: Introduction to VLSI has been developed to give students a comprehensive introduction about digital VLSI design. In this course, the fundamental knowledge in digital VLSI design is introduced, including CMOS transistors, layouts, combinational and sequential circuits, memory, design of arithmetic building blocks, timing analysis, clock distribution, etc. Students also get familiar with basic VLSI EDA (electronic design automation) tools such as OrCAD PSPICE, Mentor Graphics tools, ModelSim, Synopsys tools, etc. As portable electronics (e.g. laptops, cellp hones, PDAs, digital cameras) are becoming more and more popular, and energy conservation is receiving public awareness, low power VLSI circuit design is attracting more and more interests. We developed CPEG/EE 548: Low Power VLSI Circuit Design to introduce various low power techniques to reduce the power consumption of VLSI circuits. Nowadays the VLSI circuits can contain billions of transistors, the testing of such complex system becoming more and more challenging. We developed CPEG/EE 549: VLSI Testing to introduce various VLSI testing strategies for modern VLSI design. In addition, analog and mixed signal circuit design is becoming more and more important as MEMS (Microelectromechanical Systems) and Nano devices are integrated with VLSI into System-on-Chip (SoC) design. We developed CPEG/EE 458: Analog VLSI to introduce the analog and mixed signal VLSI design. Furthermore, we also developed EE 448: Microelectronic Fabrication to introduce the physical fabrication process of modern VLSI circuits, so that students understand how a real VLSI circuit is fabricated in the VLSI industry. With such a series of VLSI related curricula, students have an opportunity to learn comprehensive knowledge in VLSI design, fabrication and testing of VLSI circuits. Students can also accumulate hands-on experience in various EDA tools such as PSPICE, Mentor Graphics tools (Design Architect for circuit design, IC Station for layout design, and Accusim for simulation), Synopsys tools, ModelSim for VHDL/Verilog design, etc. The curricula prepare students as VLSI engineers to meet the growing demands of VLSI industry.

2. Developing VLSI Curricula in Electrical and Computer Engineering Department

To prepare students in their VLSI career to meet the challenges of modern VLSI design, fabrication and testing, a series of VLSI courses have been developed to cover comprehensive fields in VLSI technology. These courses include but are not limited to: CPEG/EE 448D: Introduction to VLSI, CPEG/EE 549: Low Power VLSI, EE 589: VLSI testing, EE 458: Analog VLSI, etc. Furthermore, EE 448: Microelectronic Fabrication is also developed to cover the fabrication processes of modern VLSI circuits. The above series of VLSI curricula prepare students with solid knowledge background and hands-on design experience in the VLSI field. The details of the above VLSI courses are introduced as below.

1). CPEG 448D: Introduction to VLSI Design

This is an introductory course to cover the fundamentals in modern digital VLSI design. Various perspectives of VLSI design are discussed, such as MOS transistors, CMOS layouts, combinational circuit design, sequential circuit design, arithmetic building blocks, interconnect, timing analysis, clock distribution, VLSI system design and logic synthesis, design for performance, etc. This course introduces to students about fundamentals in digital VLSI circuit design and performance optimization. It serves as an introductory course in VLSI field, and prepares students for other higher level VLSI courses.

Upon completing this course, students are expected to have a comprehensive understanding about digital VLSI design, analysis and performance optimization. Students also gain hands-on experience on various VLSI EDA tools, such as PSPICE, Mentor Graphics tools (Design Architect, IC Station, Accusim), ModelSim, etc.

2). CPE/EE 548: Low Power VLSI Circuit Design

With the rapid development of mobile computing, as well as the energy conservation consideration, low power VLSI design has become a very important issue in the VLSI industry. In this course, VLSI power models are introduced so that students have an in-depth understanding about the power consumption of VLSI circuits, and how we can reduce the power dissipation. A variety of low-power design methods are employed to reduce power dissipation of VLSI chips. This course is designed to cover low-power design methodologies at various design levels (from system level to transistor level). The basic low-power design strategies are introduced. Students use the learned knowledge to design low-power VLSI circuits.

Upon completion of this course, students are expected to be able to analyze the power consumption of VLSI circuits, and design low-power VLSI circuits using various strategies at different design levels. The major target is to design VLSI chips used for battery-powered systems and high-performance circuits not exceeding power limits.

3). CPE/EE 549: VLSI Testing

As VLSI continues to grow in its complexity, VLSI testing and design-for-testability are becoming more and more important issues. This course covers VLSI testing techniques such as such as VLSI fault modeling (stuck-at-fault), automatic test generation, memory testing, design for testability (DFT), etc. VLSI scan testing and built-in self-test (BIST) are also covered. Students learn various VLSI testing strategies and how to design a testable VLSI circuit.

The goal of this course is to help students get familiar with knowledge and skills in VLSI testing and validation. Students learn VLSI fault modeling, testing strategies for combinational/sequential circuits, memory, and analog circuits. Some important topics such as delay testing, design for testability (DFT), built-in self-test (BIST) and boundary scan standard are also discussed. Upon completion of this course, students are expected to be able to effectively test VLSI systems using existing test methodologies, tools and equipments.

4). CpE/EE 458: Analog VLSI Circuit Design

Analog circuits are very important for the front and back ends to interface to the outside world. The system-on-chip (SoC) technology requires the implementation of both digital and analog modules on a single chip. The goal of this course is to introduce the modeling, design and analysis of analog CMOS VLSI. The students design analog VLSI layouts, extract the netlists and simulate the circuit behavior. The transistor sizing in analog VLSI layouts is also discussed.

Upon the completion of this course, students are able to design and analyze basic analog and mixed-signal CMOS VLSI circuits. They get to know various analog/mixed-signal VLSI circuits such as current sources and sinks, amplifiers, S/H circuits, switching-capacitance circuits, analog-to-digital and digital-to-analog converters, etc. They are expected to be able to design analog VLSI layouts, decide transistor sizing, and simulate the designed VLSI circuits.

5). ELEG-448: Microelectronic Fabrication

This course covers basic microelectronic fabrication processes for semiconductor and VLSI technologies, including photolithography, plasma and reactive ion etching, ion implantation, diffusion, oxidation, evaporation, vapor phase epitaxial growth, sputtering, and CVD. Advanced processing topics such as next generation lithography, MBE, and metal organic CVD are also introduced. The physics and chemistry of each process are introduced along with descriptions of the equipment used for the manufacture of integrated circuits. The integration of microfabrication process into CMOS, bipolar, MEMS and nanotechnologies is also discussed.

The purpose of this course is to provide students with technical background and knowledge in silicon microelectronic fabrication process. Fabrication processes on Microelectromechanical System (MEMS) and nanotechnology are also introduced. Upon finishing this course, students are expected to be familiar with the basic semiconductor and VLSI microfabrication processes. They can explain the physical and chemical mechanism for the fabrication process, and understand the basic procedures of the process.

3. Results and Discussions

VLSI courses generally involve heavy design projects for students to get familiar with the various EDA tools. As a result, the computer support is very essential for VLSI course curriculum. The School of Engineering in our university has 6 general computer laboratories which can be used for VLSI design and simulation. The computer labs totally have 135 desktop PCs and 20 Ultra25 Sun Microsystems workstations. The PCs are equipped with Windows XP and Redhat Linux dual operating systems. Various EDA tools are available to students. All the computer labs are equipped with ceiling projectors with multimedia support, and network printers.

A Digital Design Laboratory is also available, which is equipped with 10 workstations. Each has a PC, programmable Altera boards, 2 power supplies, and oscilloscope, function generator, different kinds of TTL chips, Altera boards, Xilinx boards, multimeteters, and other related hardware. Furthermore, we have a Microprocessor Laboratory/Embedded Systems Laboratory. It has 10 stations. Each has a personal computer, function generator, oscilloscope and multimeter. It also has 15 Microchip boards used in the microprocessor class, 10 micro-controller, 2 EPROM programmers, 1 ultraviolet erasers, 2 development centers and more boards and many other hardware. It has Assembly emulators, Altera in full and student versions, etc. We also have a Circuits (I and II) Laboratory used to for basic electronics/digital applications. It has 10 workstations. Each one has: a PC, programmable Altera/Xilinx boards, 2 or more power supplies, oscilloscope, function generator, different kinds of TTL chips, multi-meters. The laboratory has many diverse/different chips, ICs and motors. These software and hardware support are very helpful for students in their VLSI courses. Students can apply the knowledge they learned from the class into real VLSI experiments.

For the microelectronic fabrication, currently we don't have the fabrication facilities yet. But we bought the videos and use Multimedia to help students understand the concepts. For example, we play the video of "Making of a Microchip" by Texas Instruments. This video shows the real fabrication facilities and processes in modern VLSI industry. This is very helpful for students to understand the concepts.

During the teaching of above courses, we notice that students come from various backgrounds, and some of them may need extra help in those EDA tools or VLSI fundamentals. Thus, at the beginning of each semester, we generally spend 1~2 weeks introducing the VLSI fundamentals to help students refreshing their memory in VLSI field. Very detailed tutorials have also been designed for students to get familiar with various EDA tools (such as PSPICE, Mentor Graphics tools, ModelSim, Synopsys tools, etc.). Several sections of lab tutorials have been arranged to help students get familiar with the tools. Some small and simple circuits are used as examples (e.g. inverter, NAND gate) to explain how the layout and schematic can be designed step by step in EDA tools, and how to perform the simulation. This has been proven to be very helpful for students. Using these simple examples, students can quickly understand the idea and start working with the big course projects in the class.

The above VLSI curricula have been proven to be very popular among students. Students demonstrated tremendous interests in these courses. Each semester, the course registration for these courses has been full in the very early days of registration. The department had to open extra sessions to accommodate those students who are very interested in these program. The student feedback and course evaluation for these VLSI courses have been fantastic. To name a few, students rated these courses "one of the best courses they have taken in the school", "very interesting and useful", "feeling very happy for entering such an exciting field". The courses have also been praised and received excellent reviews in the peer review by the colleagues in School of Engineering. The courses have been rated as very effective in the teaching outcomes.

VLSI is an active research field, and each year tens and hundreds of thousands research papers have been published in VLSI field. During the teaching, students are also encouraged to explore the most recent research frontiers in the VLSI field. Students are asked to do some background survey, search for most recent research papers in the field (e.g. low power VLSI, VLSI testing, etc.), and share their findings in the class. Through the discussion, they know the most recent research activities in the field. This also help them to find possible research issues in the VLSI field, and trigger their interest to further dig into the VLSI research. Many students eventually use the topics they find in their master project/thesis research, and achieved excellent results. They published some posters/papers in academic conferences/journals, and won the awards in the ASEE student poster competitions in the recent years. For example, a master student did her research in Gated Clock low power technique. She performed PSPICE power simulation for both sequential circuits with and without gated-clock low power technique. The simulation results demonstrated that gated clock technique led to effective power savings for the given input pattern sequences. The results were published in ASEE'09 Northeast Section conference [6], and won the 2^{nd} prize in the best student poster competition. The layout design of the circuit with gated clock technique is shown in Figure 2.

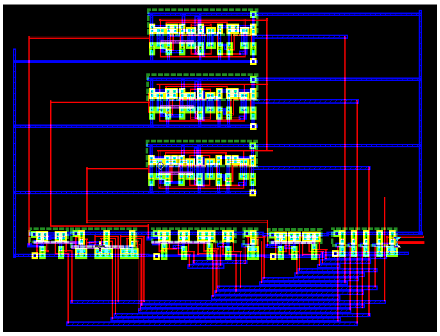

Figure 2. Layout design of a sequential circuit with gated-clock technique [6]

Another student did his research in 8-bit low power Wallace tree multiplier design, and published his results in a student poster in ASEE'08 conference [7]. The schematic design of the Wallace tree multiplier in PSPICE is shown in Figure 3.

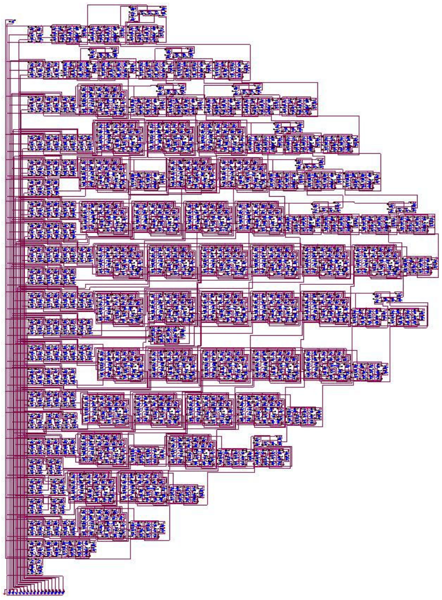

Figure 3. Schematic design of 8-bit Wallace-tree multiplier [7]

Furthermore, the VLSI courses are open for students in both electrical and computer engineering departments. Many courses are cross-linked so that students from either background can register for the courses. Students from electrical engineering background may have a better understanding on the physical working mechanisms of the transistors, and the physical behavior of the circuits. However, students from computer engineering background may have a better understanding on the VHDL or Verilog coding and logic synthesis of the circuits. After the courses, students from both backgrounds have a comprehensive understanding about VLSI technologies.

VLSI projects are generally accomplished by a team instead of individual engineers. This is due to the fact that modern VLSI circuits can easily contain millions or billions of transistors. As a result, group projects are arranged for students to accumulate team collaboration skills. They need to collaborate with other team members in the project, and assign the task for each member. This helps them accumulate collaboration spirits and skills, so that they are well-prepared for the real challenges in the VLSI industry.

VLSI course projects generally involve heavy work-load. For example, VLSI layout design is very time-consuming and the layout debug can be a painful experience. However, students can also learn a lot from the layout design. In order to encourage students to explore more from the projects, some extra work is generally arranged as optional bonus part. For example, in a low power VLSI project, students are asked to design a CMOS full adder both in static CMOS and dynamic domino architectures, and compare the power consumption of both circuits. Students are not required to design the layouts. They can perform the power simulation using the schematics only. But if they choose the layout option, their results will be more accurate and they will get 15 extra bonus points. This bonus option actually encourages students to explore more from the projects. During the teaching, it was found that around 1/3 of the students in the class eventually complete the layout design. In the feedback survey, they claimed that they learned a lot from the class through the layout design experience.

4. Conclusions and Future Work

In this paper, the development of VLSI curricula in Electrical and Computer Engineering department is introduced. A series of VLSI courses have been developed. These courses include but are not limited to: CPEG/EE 448D: Introduction to VLSI, CPEG/EE 549: Low Power VLSI, EE 589: VLSI testing, EE 458: Analog VLSI, etc. Furthermore, EE 448: Microelectronic Fabrication is also developed to cover the fabrication processes of modern VLSI circuits. The course descriptions and the goals of these courses are discussed in details. The above series of VLSI curricula prepare students with solid knowledge background and hands-on design experience in the VLSI field. The VLSI curricula have triggered intensive interests among students, and the student feedbacks for these courses have been outstanding. The teaching of above courses has also triggered students' interest in active VLSI research. Based on students' master projects/thesis research, various student posters/papers have been published in academic conferences and journals.

In the future, we plan to further develop some more VLSI courses, such as VLSI Design Automation, and VLSI Digital System Design, etc. We are also planning to arrange a multi-semester project to cover both the VLSI design and testing. In the VLSI design course (e.g. CPEG/EE 448D Introduction to VLSI, or CPEG/EE 548 Low Power VLSI), students are asked to design the physical layouts of VLSI circuits. Once the designs are completed, students will submit their designs to MOSIS [8] for fabrication. In the next semester, students will take the VLSI testing (CpE/EE 549) course. When the real fabricated chips are shipped back to students, they will utilize the knowledge they learned in VLSI testing class to thoroughly test the fabricated circuits. This will be very helpful for students to understand the full cycle of modern VLSI design, simulation, fabrication and testing.

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Appendix

1). Topics and Lab Projects of CPEG 448D: Introduction to VLSI Design

Topics: The topics covered in this course include

- MOS transistors working principles.
- CMOS inverter
- CMOS layout and fabrication process
- Designing combinational logic circuits
- Designing sequential logic circuits
- Design for performance: delay models, critical path analysis
- Coping with Interconnect
- Designing arithmetic building blocks
- Designing memory and array Structures
- Timing issues in digital circuits, clock distribution, self-timed circuits
- VHDL design of digital system, synthesis, timing analysis/optimization
- Design for low power
- Design for Testability

Lab Projects: There are several projects on VLSI system design. Students design the schematic and layout of an example combinational circuit and a sequential circuit. Students also design a digital microprocessor using VHDL, and obtain the gate-level netlist by logic synthesis. The timing analysis and design optimization of the microprocessor are also be performed. Through these projects, students learn various design strategies for modern very large scale digital VLSI systems.

2). Topics and Lab Projects of CPE/EE 548: Low Power VLSI Circuit Design

Topics: The topics covered in this course include

- Modeling and sources of power consumption (transition power, short-circuit power and static power)
- Power estimation at different design levels (circuit, transistor, and gate levels)
- Using PSPICE for power simulation
- Power optimization for combinational circuits
- Power optimization for sequential circuits (logic shut-down, gated-clock technique, etc.)
- Power optimization for RT and algorithmic levels
- Circuit and layout level for low power
- Software design for low power
- Low power random access memory circuits
- Leakage power consumption in deep sub-micron technologies
- Power analysis and design at system level

Lab Projects: Three lab projects on low power VLSI design and simulation are assigned. The goal of the projects is to help student accumulate skills and experience in low power VLSI design. Students implement the low power strategies they learned from the class in their circuit design. Through these projects, students learn how to estimate the power consumption of a circuit, and how to reduce the power consumption in their design. Students design both static CMOS and dynamic domino full adder, and perform PSPICE power simulation to compare the power consumption of both architectures. Students also design a sequential circuit and apply logic shut-down technique to see how much power can be saved for the given input patterns. The final project includes the design of a reasonable-size low-power digital system by a team of 2 students.

3). Topics and Lab Projects of CPE/EE 549: VLSI Testing

Topics: Topics covered in this course include

- VLSI Testing Process and Test Equipment.
- Test Economics and Product Quality.
- Fault Modeling (single stuck-at-fault, etc).
- Logic and Fault Simulation.
- Testability Measurements.
- Combinational Circuit Test Generation (D-algorithm, PODEM algorithm, FAN algorithm, etc.)
- Sequential Circuit Test Generation.
- Memory Testing.
- Delay Testing.
- IDDQ Testing.
- Design for Testability.
- Digital DFT and Scan Design.
- Built-In Self-Test.
- Boundary Scan Standard.

Lab Projects: Several projects on VLSI testing are assigned. VLSI EDA tools (Synopsys tools) are used for projects. The goal of the projects is to help student accumulate skills and experience in VLSI testing and validation. Students design a combinational circuit, and use Synopsys ATPG (Automatic Test Pattern Generation) tool to find the minimum test set with certain fault coverage. Students also perform a boundary scan testing on a given circuit design, and see how they can enhance the testability of the design. Students use the knowledge they learned in the class for testable designs of VLSI circuits.

4). Topics and Lab Projects of CpE/EE 458: Analog VLSI Circuit Design

Topics: The topics covered in this course include

- Integrated-circuit devices and modeling
  - ✓ MOS transistors
  - ✓ Resistors, capacitors, MOSFET working principles and characteristics.
  - ✓ MOS device modeling
- Processing and layout
  - ✓ CMOS processing
  - ✓ CMOS layout and design rules, layout matching
- Basic current mirrors and single-stage amplifiers.
  - ✓ Simple CMOS current mirror
  - ✓ Amplifiers
  - ✓ Differential amplifiers
- Basic OPAMP design and compensation.
  - ✓ Two-stage CMOS OPAMP
  - ✓ Feedback and OPAMP compensation
- Comparators
- Sample and holds (S/H), voltage references, and translinear circuits.
- Discrete-time signals and switched-capacitor circuits.
- Data converter fundamentals (DAC/ADC architectures).
- Nyquist-rate D/A and A/D converters.
- Continuous-time filters

Lab Project: Several lab projects on VLSI design and simulation are assigned. The goal of the projects is to help student accumulate skills and experience in analog VLSI design and simulation. Students use EDA tools (Cadence OrCAD PSPICE, Mentor Graphics Tools, etc.) to design the VLSI circuits, and simulate its response. The projects include design and simulation of a CMOS single-stage amplifier, OPAMP design optimization, as well as an analog-to-digital converter design. Through the projects, students get familiar with analog/mixed-signal VLSI design and simulation.

5). Topics of ELEG-448: Microelectronic Fabrication

Topics: The topics covered in this course include

- An overview of microelectronic fabrication.

- Preparation of silicon wafers
- Patterning process: photolithography.
- Thermal oxidation of silicon.
- Diffusion.
- Ion implantation.
- Rapid thermal processing (RTP), annealing,
- Film deposition (PVD, CVD, epitaxy).
- Interconnections and contacts.
- Packaging and yield.
- CMOS process integration: CMOS VLSI fabrication.
- Bipolar process integration.
- Micromachining for Microelectromechanical Systems (MEMS).
- Nanofabrication for nanotechnology devices.